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Renewable and Sustainable Energy Reviews
12 (2008) 2495–2504

RENEWABLE
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ENERGY REVIEWS

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Wind power potential assessment for three locations in Algeria

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Received 15 May 2007; accepted 21 June 2007

Abstract

This paper utilized wind speed data over a period of almost 10 years between 1977 and 1988 from three stations, namely Adrar, Timimoun and Tindouf to assess the wind power potential at these sites. The long-term annual mean wind speed values along with the wind turbine power curve values were used to estimate the annual energy output for a 30 MW installed capacity wind farm at each site. A total of 30 wind turbines each of 1000 kW rated power were used in the analysis. The long-term mean wind speed at Adrar, Timimoun and Tindouf was 5.9, 5.1 and 4.3 m/s at 10 m above ground level (AGL), respectively. Higher wind speeds were observed in the day time between 09:00 and 18:00 h and relatively smaller during rest of the period. Wind farms of 30 MW installed capacity at Adrar, Timimoun and Tindouf, if developed, could produce 98,832, 78,138 and 56,040 MWh of electricity annually taking into consideration the temperature and pressure adjustment coefficients of about 6% and all other losses of about 10%, respectively. The plant capacity factors at Adrar, Timimoun and Tindouf were found to be 38%, 30% and 21%, respectively. Finally, the cost of energy (COE) was found to be 3.1, 4.3 and 6.6 US cents/kWh at Adrar, Timimoun and Tindouf, respectively. It was noticed that such a development at these sites could result into avoidance of

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1364-0321/$ - see front matter
doi:10.1016/j.rser.2007.06.007

48,577, 38,406 and 27,544 tons/year of CO_2 equivalents green house gas (GHG) from entering into the local atmosphere, thus creating a clean and healthy atmosphere for local inhabitants.

Keywords: Wind energy assessment; Wind speed; Plant capacity factor; Wind farm; Green house gases; Renewable energy

Contents

1. Introduction

An accurate wind resource assessment is an important and critical factor to be well understood for harnessing the power of the wind. It is well known that an error of 1% in wind speed measurements leads to almost 2% error in energy output. As we know that wind resources are seldom consistent and vary with time of the day, season of the year, height above the ground, type of terrain, and from year to year, hence should be investigated carefully and completely. According to Tennis et al. [1], the wind resource assessment powering a wind farm project is as fundamental to the project's success as rainfall is to alfalfa production. So, one who is interested in a wind farm development should know that how strong are the winds at the site of interest and how much energy will the wind farm produce in these winds. Potts et al. [2] performed the wind resources assessment of Western and Central Massachusetts using WindMap software which is based on geographic information systems (GIS). The authors utilized wind speed data from five locations and upper air data from one location as input to WindMap software to produce estimates of wind speed at 50 m. Brower [3] used GIS-based tools to develop wind resource map for New Mexico using wind speed data from 67 stations and elevation data in the region.

Rehman [4] presented the energy output and economical analysis of 30 MW installed capacity wind farms at five coastal locations in terms of unadjusted energy, gross energy, renewable energy delivered specific yield and plant capacity factor using wind machines of 600, 1000 and 1500 kW. In another study, Rehman [5] performed a detailed analysis of wind speed in terms of energy yield, effect of hub height on energy yield, plant capacity factor, etc. for an industrial city situated on the northwest coast of Saudi Arabia. Rehman and Aftab [6] performed detailed wind data analysis for wind power potential assessment for five coastal locations in Saudi Arabia. Rehman et al. [7] computed the cost of energy generation at 20 locations in Saudi Arabia using net present value approach. Rehman and Halawani [8] presented the statistical characteristics of wind speed and its diurnal

variation. The autocorrelation coefficients were found to match the actual diurnal variation of the hourly mean wind speed for most of the locations used in the study. Rehman et al. [9] calculated the Weibull parameters for 10 anemometer locations in Saudi Arabia and found that the wind speed was well represented by the Weibull distribution function. With growing global awareness of the usage of clean sources of energy, wind energy in particular, a lot of work is being carried out in different parts of the world, as can be seen from [10–24].

In Algerian context, a company of electricity, SONELGAZ, has used photovoltaic-based solar energy to power the isolated villages and remote houses of south Algeria. These locations include Adrar, Timimoun (Tala Hamou-Moussa) and Tindouf (Gara Djebilet, Hassi Mounir, Draa el Khadra) as reported by Himri [25]. At present, the SONELGAZ Company is leading the way towards the development and utilization renewable sources of energy in the country in general and wind energy in particular as can be seen from Haddouche et al. [26] and SONELGAZ [27]. According to Elimax [28], Algeria is among 15 African countries (South Africa, Eritrea, Mauritania, Cap avert, Algeria, Lesotho, Seychelles, Madagascar, Somalia, Djibouti, Morocco, Chad, Egypt, Maurice, Tunisia) which have the good potential of wind energy.

This paper presents the wind data analysis and available wind energy potential at three locations, namely Adrar, Timimoun and Tindouf in Algeria. The wind energy potential was assessed using a hypothetical wind farm of 30 MW installed capacity consisting of 30 wind turbines of 1 MW rated power each from DeWind [29]. The energy yield was calculated using the RetScreen [30] software and finally the plant capacity factors and economical parameters were estimated and reported.

2. Wind data and site description

The wind speed data were collected over a period of 8–10 years at three sites used in this study. The latitude, longitude, altitude, measurement duration and years of measurements are summarized in Table 1. The wind speed measurements were made 10 m above ground level (AGL) and recorded every 3 h interval (viz. 0, 3, 6, 9, 12, 15, 18 and 21 h) at all the stations. The wind data measurement stations lie in the south-west region of Algeria. The geographical locations of these stations are also shown in Fig. 1.

The diurnal change in long-term mean wind speed at Adrar, Timimoun and Tindouf stations is shown in Fig. 2. The maximum wind speed was found to occur at 09:00 h at all the locations while the minimum at 21:00 h. In general, higher winds were observed between 09:00 and 18:00 h while lower during rest of the the day. This indicates that higher electricity could be produced during 09:00–18:00 h, which also coincide with higher electricity demand time. It is also evident from this figure that wind speed was highest at

Table 1
Geographical coordinates of the data collection stations used in the study

Location	Latitude (deg)	Longitude (deg)	Altitude (m)	Duration (years)	Measurement years
Adrar	27°49′N	00°17′E	263	11	01/01/1977–07/12/1988
Timimoun	29°15′N	00°17′E	312	11	01/01/1977–31/12/1988
Tindouf	27°40′N	08°06′W	401	8	01/01/1976–01/12/1984

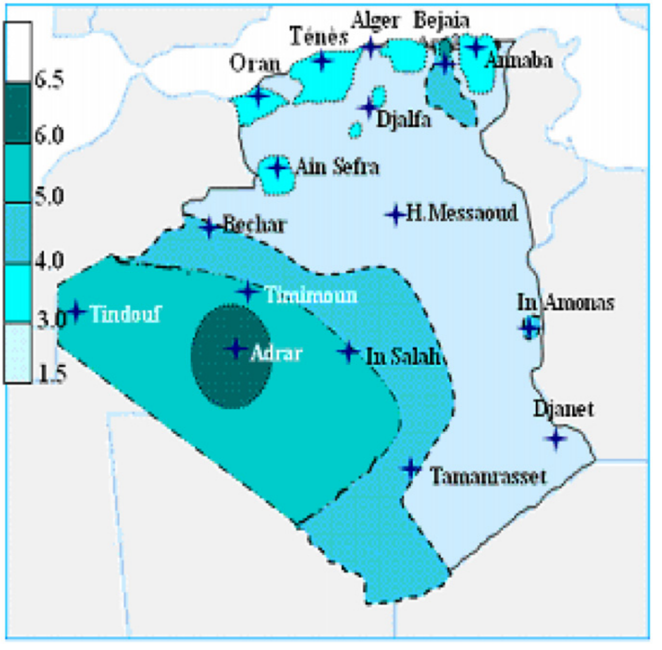


Fig. 1. Map showing the locations of the wind measurement stations.

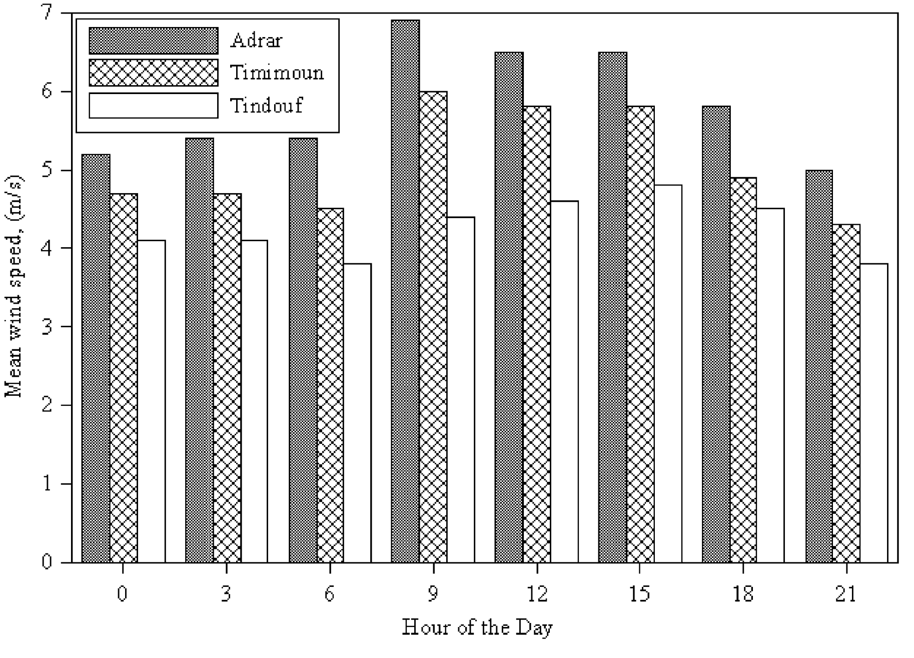


Fig. 2. Diurnal variation of long-term mean wind speed.

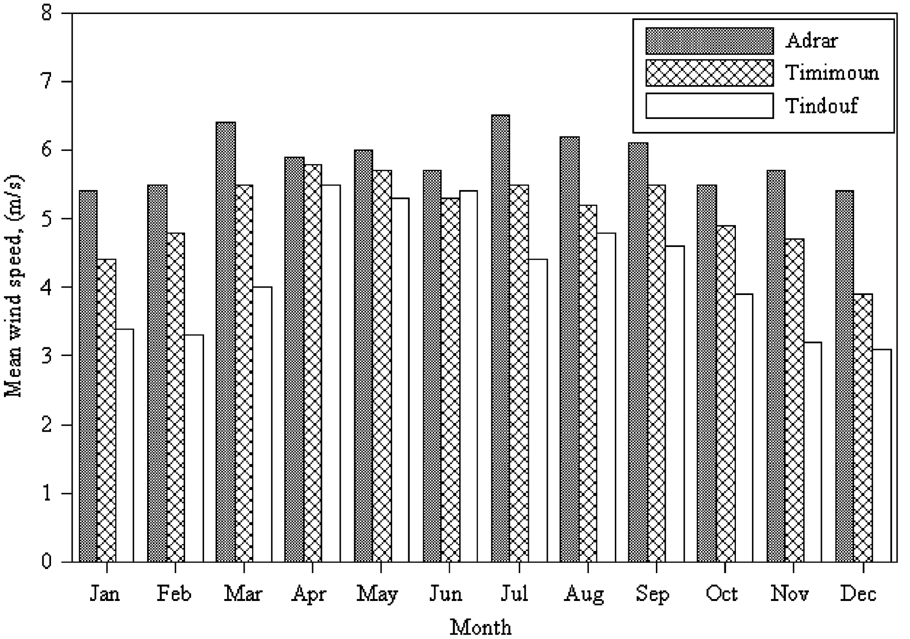


Fig. 3. Seasonal variation of long-term mean wind speed.

Ardar while lowest at Tindouf during the entire day. The seasonal variation of wind speed provides information about the availability of wind speed during different months of the year which helps in planning the operation of existing power plants in coordination with the wind power plant. Fig. 3 provides the variation of monthly average wind speed during entire data collection period at three stations under consideration in this study. Again, highest wind speeds were found at Adrar whiles the lowest at Tindouf during the year. The monthly mean wind speed was found in between the two stations, as seen from Fig. 3.

3. Wind energy yield estimation

The energy yield from a hypothetical wind farm of 30 MW installed capacity is obtained from RetScreen software. The software requires the wind turbine wind power curve, the annual average wind speed, the rotor swept area, the mean temperature and pressure, hub height, etc. The wind turbine-related parameters are summarized in Table 2. The wind power curve of the DEWIND 62 wind turbine, obtained from Ref. [30], is depicted in Fig. 4. Fig. 4 shows that wind turbine starts generating power at a cut-in-speed of 3 m/s and reaching its rated capacity at 11.5 m/s and continues to produce rated power up to a wind speed of 16 m/s. At further higher wind speeds, the power yield decreases, as can be seen from Fig. 4.

The various types of losses like array, airfoil soiling, icing, down time and miscellaneous were also considered in the estimation of wind energy and are summarized in Table 3. The pressure and temperature adjustment coefficients, which affect the energy yield, were also taken into consideration, as listed in Table 3. A value of 0.16 for wind shear exponent was

Table 2
Wind turbine parameters [30]

Item	Value
Model	DEWIND 62
Rated power (kW)	1000
Rotor diameter (m)	62
Hub height (m)	68.5
Swept area of rotor (m^2)	3019
Cut-in-wind speed (m/s)	3
Rated wind speed (m/s)	11.5
Cut-out-wind speed (m/s)	23
Rotor speed (rpm)	12.1–25.2
Tower type	Tubular

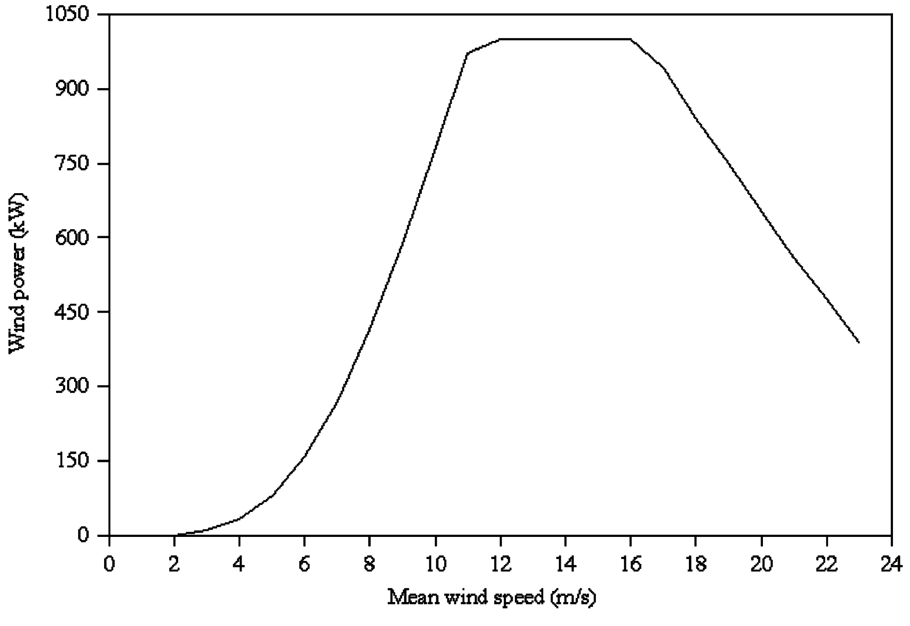


Fig. 4. Wind power curve of DeWind turbine DEWIND 62 [30].

Table 3
Wind energy related coefficients used in energy yield estimation

Item	Value
Array losses (%)	3
Airfoil soiling and/or icing losses (%)	2
Downtime losses (%)	2
Miscellaneous losses (%)	2
Pressure adjustment coefficient	0.97
Temperature adjustment coefficient	0.97
Wind shear exponent	0.16

Table 4
Summary of energy yield and related output from wind farm of 30 MW

Item	Adrar	Timimoun	Tindouf
Annual mean wind speed (m/s)	5.9	5.1	4.3
Specific yield (kWh/m^2)	1091	863	619
Gross energy yield (MWh/year)	109,371	86,470	62,015
Wind energy delivered (MWh/year)	98,832	78,138	56,040
Plant capacity factor (PCF) (%)	38	30	21
Green house gases (GHG) (tons/year)	48,577	38,406	27,544

used to estimate the wind speed at the wind turbine hub height. The wind energy yield and other relevant output parameters from the model are summarized in Table 4. The specific energy yield from Adrar, Timimoun and Tindouf was found to be 1091, 863 and 612 kWh/m^2, respectively. The annual gross energy yield, without losses, from the hypothetical wind farm of 30 MW installed capacity at three locations in above order was 109,371, 86,470 and 62,015 MWh, respectively. The actual renewable energy delivered, after losses, at these sites was found to be 98,832, 78,138 and 56,040 MWh each year, as given in Table 4. The plant capacity factors were found to be 38%, 30% and 21% at these sites. Furthermore, the usage of wind energy at these sites will avoid 48,577 tons of green house gases (GHG) from entering into the local atmosphere of Adrar each year and about 1,214,425 tons of GHG over the lifetime of the wind power plant. Similarly, at Timimoun and Tindouf, a total of 960,150 and 681,500 tons of GHG could be avoided from entering into the local atmosphere of these stations.

4. Wind energy economical analysis

The RetScreen model is capable of performing a detailed economical analysis of the wind energy yield using some cost and interest parameters such as initial cost, discount and inflations rates, GHG emission reduction credit, project life time, etc. The details of the cost of various items involved in the development of a wind farm, as given in Ref. [30], are assumed to be valid for three locations in Algeria, are summarized in Table 5. As seen from this table, around 74% of the total wind power plant cost accounts for energy equipment like wind turbines and other electrical equipment. The second major part of the cost of about 14% accounts for balance of plant (BOP) cost. The inflation and discount rates of 2.5% and 12%, used in the present study, along with other cost parameters are summarized in Table 6. The annual operation and maintenance cost is taken as US$770,000, as given in Ref. [30]. The pre-tax internal rate of return (IRR) and return on investment (ROI) was found to be 61.7%, 42.1% and 22.8% for Adrar, Timimoun and Tindouf sites, respectively, as given in Table 7. The after-tax values were also found to be the same as pre-tax values of IRR and ROI. The simple payback period and year-to-positive cash flow were found to be minimum for Adrar and maximum for Tindouf areas. The net present values for Adrar, Timimoun and Tindouf were found to be US$76,125,725, 48,843,997 and 19,712,439, respectively, as given in Table 7.

Table 5
Cost of wind farm development [30]

Cost item	Amount ($)	Percent of total cost (%)
Feasibility study	245,200	0.6
Development	835,500	2.0
Engineering	610,500	1.4
Energy equipment	31,890,000	74.7
Balance of plant	5,868,000	13.8
Miscellaneous	3,215,110	7.5
Initial costs–total	42,664,310	100.0

Table 6
Summary of economic input parameters for cost analysis [30]

Items	Value
Avoided cost of energy ($/kWh)	0.0950
RE production credit ($/kWh)	0.025
RE production credit duration (year)	10
RE credit escalation rate (%)	2.5
GHG emission reduction credit ($/$t_{CO_2}$)	5.0
GHG reduction credit duration (year)	21
GHG credit escalation rate (%)	0.0
Energy cost escalation rate (%)	5.0
Inflation (%)	2.5
Discount rate (%)	12.0
Project life (year)	25
Annual operation and maintenance cost ($/year)	770,000

Table 7
Summary of economical feasibility indicators for a 30 MW installed capacity wind farm at three locations

Item	Value		
	Adrar	Timimoun	Tindouf
Pre-tax IRR and ROI (%)	61.7	42.1	22.8
After-tax IRR and ROI (%)	61.7	42.1	22.8
Simple payback (year)	3.8	4.8	7.0
Year-to-positive cash flow (year)	1.8	2.7	5.7
Net present value—NPV ($)	76,125,725	48,843,997	19,712,439
Annual life cycle savings ($)	9,706,028	6,227,608	2,513,335
Benefit–cost (B–C) ratio	6.95	4.82	2.54
Cost of energy (COE) ($/kWh)	0.0309	0.0430	0.0657

5. Conclusions

The present study performed the energy yield and economical analysis of a hypothetical wind farm consisting of 30 wind turbines of 1 MW rated power each from DeWind using

the long-term annual mean wind speed data at three locations, viz. Adrar, Timimoun and Tindouf in Algeria. The study found the following salient features as the outcome of the analysis:

- The long-term mean wind speed at Adrar, Timimoun and Tindouf was 5.9, 5.1 and 4.3 m/s at 10 m above ground level (AGL).
- The higher wind speeds were observed in the day time between 09:00 and 18:00 h and relatively smaller during rest of the period.
- The long-term seasonal wind speeds were found to be relatively higher during March–September compared to other months.
- Wind farms of 30 MW installed capacity at Adrar, Timimoun and Tindouf, if developed, could produce 98,832, 78,138 and 56,040 MWh of electricity annually taking into consideration the temperature and pressure adjustment coefficients of about 6% and all other losses of about 10%, respectively.
- The plant capacity factors at Adrar, Timimoun and Tindouf were found to be 38%, 30% and 21%, respectively. The corresponding cost of energy at these three sites was found to be 3.1, 4.3 and 6.6 US Cents/kWh.
- Such a development at these sites could result into avoidance of 48,577, 38,406 and 27,544 tons/year of CO_2 equivalents GHG from entering into the local atmosphere thus creating a clean and healthy atmosphere for local inhabitants.
- The economical feasibility study made based on the assumed economical parameters from the literature, showed that the positive cash flow could be obtained in 1.8, 2.7 and 5.7 years at Adrar, Timimoun and Tindouf, respectively, with corresponding benefit cost ratio (B–E) of 6.95, 4.82 and 2.54.

Acknowledgements

The authors wish to acknowledge the support of Research Institute of King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia and Mr. S. Guezane and Mrs. R. Aissaoui at CREDEG/Direction Etudes & Développement SONELGAZ for their cooperation.

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